International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 11, Number 1 (2018), pp. 51-62

http://www.irphouse.com

Using the Increasing of Renewable Energy Sources (Wind and Solar) in the Egyptian Power System for the Environmental Improvement

Mahmoud M. Abdella[a,*] and Ibrahim A. Nassar[b]

[a] *Power Department, Suez Canal Authority, Ismailia, Egypt.*

[b] *Department of Electrical Power and Machine, Faculty of Engineering, Al-Azhar University, Nasr City, Cairo, Egypt.*

*(*Corresponding Author)*

Abstract

Electrical energy is considered the main pillar to achieve comprehensive and ongoing renaissance. Therefore, the Egyptian Electricity Holding Company (EEHC) is exerting much effort to add annual achievements in the form of various projects of energy i.e., production, transport and distribution, taking into account optimal operation of all network functions. The EEHC has paid great attention to renewable energy since it is a global perspective for being positives in terms of environmental improvement, reduction of harmful emissions and overcoming the depletion of petroleum resources. The available renewable energy sources were evaluated and its technologies were provided to take advantage of what is available from renewable energy sources. The EEHC Strategy aims to increase the proportion of power totally generated from renewable energy to 20% by 2022, the wind farms 12% and solar power 2%. This paper aims at studying the positive aspects resulting from the establishment of this amount of renewable energy by 2022. The emission factor of the Egyptian grid, the expected annual CO2 Emission Reductions (ER), Certified Emission Reduction (CER) and the amount of fuel saving provided by renewable energy are calculated.

Keywords*:* - Renewable Energy, Emission Factor, Emission Reductions, Egyptian grid and Fuel Saving

1. INTRODUCTION

As The Thermal power plants (Steam, Gas and Combined), of the Egyptian network, are considered the main power in terms of about 90% of the total generated power

beside 8% Hydro power plants and 2% renewable energy (Wind and Solar). Gas stations produce 14% of the total generation power in the Egyptian network as shown in Fig. **(1)** [1]. The Egyptian network transfers power through three transmission networks (500kv, 220 kv and 132 kv). They are interconnected through transformers (500/220 kv, 500/132 kv and 220/132 kv). The power generation from thermal station has been increased from 81565 GWh in 2006 to about 144995 GWh in 2015. The peak load increased from 17300 MW in 2006 to 28015 MW in 2015. This was countered with an increase of the generated power from 108368 GWh to about 174875 GWh and the fuel consumption increased from 18448 Tonne of Oil Equivalent (toe) to 34110 ktoe in the same period as shown in Fig. (**2**) [1-5].

As a result of recent gas discoveries in Egypt, which contributed to increase the reserves of natural gas to about 66 trillion cubic feet. thus, the general trend in this regard has become to use the natural gas as a main fuel in combined cycle power plants (CCPP), which represent 65% of total fuel consumption (22137 ktoe). Oil has lost much of its importance as a major fuel for power plants generation. Most oil fired power plants are turned to operate with natural gas as the main fuel.

Heavy and light fuel oil represents 25% (22137 toe) and 1.4% (478 toe) of the total fuel consumption respectively.

The total loss in the Egyptian network on the transmission and distribution level reached to 11.77% at 2014 and become 12.88% in 2015. The Egyptian network includes over 45 power stations which incorporate hydraulic, steam, gas, combined, solar as well as wind farm plants [1]. Different projects of power stations, substations, and transmission lines besides upgrading the existing projects have been carried out [6, 7].

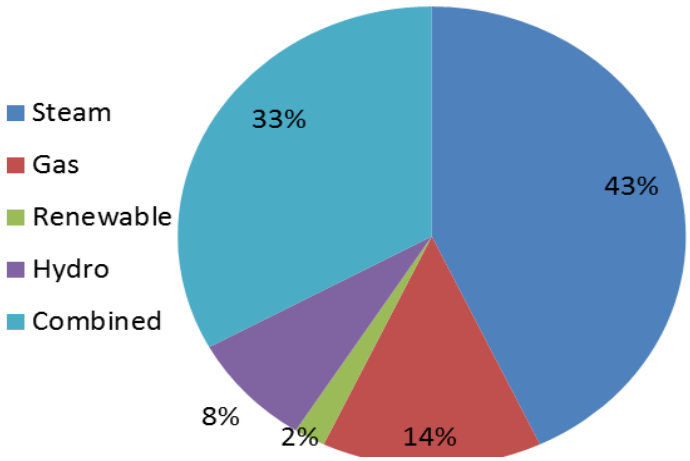

Fig. 1. Egyptian networks generation types

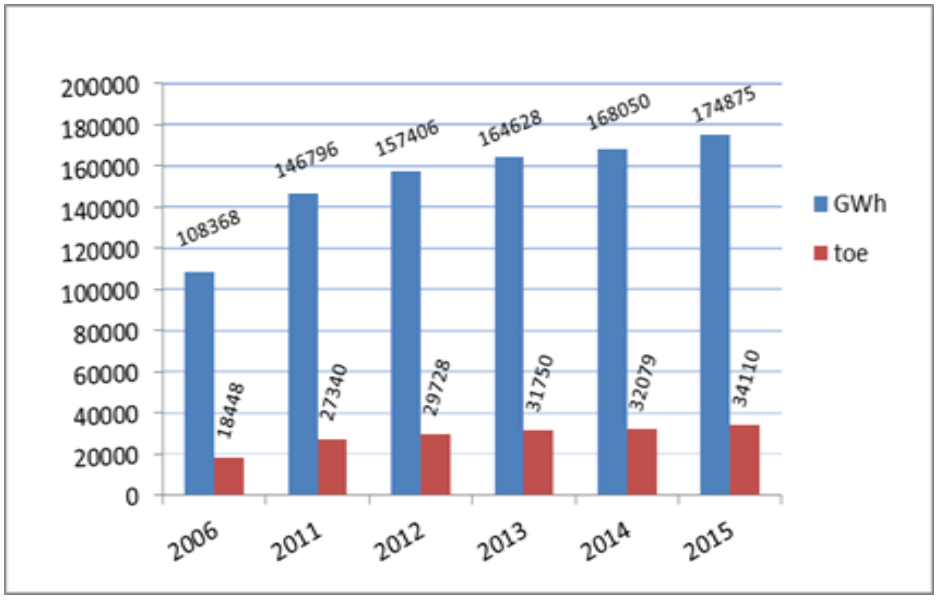

Fig. 2. Development of generation and fuel consumption

2. EGYPTIAN RENEWABLE ENERGY

The Strategy of EEHC is based on the diversification of energy sources and expanding the use of renewable energy sources, especially hydro, wind and solar energy. The renewable energy increased from 13196 GWh in 2006 to 15266 GWh in 2015 [1-5].

2.1. *Hydro Power Plant*

Hydro power is available in Upper Egypt through the Nile River. EEHC has certified the work of the hydropower projects on water level difference. There are 5 hydro power plants in upper and middle Egypt zone of the EEHC with total capacity up to 2800 MW. The total hydro power generated in 2006 was 12644 GWh (11.67% of total power generated),while in 2015, it was 13822 GWh (7.9 % of total power generated) [1-5].

2.2. *Wind Power Plant*

Egypt has an abundance of wind resources in the Gulf of Suez, which is considered among the best locations in the world with high and regular speeds. The area in the west of the Gulf of Suez is promising to set up big wind projects, where the average wind speed is up to 8-10m / s. As it is unpopulated, it is allowed to establish future wind projects. There are also promising areas east and west of the Nile Valley where the average wind speed is up to 7-8 m / s [1]. Fig. (**3**) shows wind Atlas in Egypt [8-11].

EEHC started to exploit Zafarana area in the Gulf of Suez to construct the wind farms. The development of the annual output was about 552 GWh in 2006 and 1444 GWh in 2015 with total installed capacity up to 547 MW [1-5]. As for future projects, the EEHC had developed a future plan to expand the establishment of wind projects in areas of the Gulf of Suez and the Nile Valley, bringing the total installed capacity of wind power to 12% (7200 MW)of the total power generated by 2022. Table-**4** shows the annual proposed projects capacity down to the year 2022 [12-14].

2.3. *Solar Energy*

Of the Sun belt countries region, Egypt is suitable for solar energy applications. Egypt solar Atlas was issued for having readings, that have been restricted for years for all Republic areas

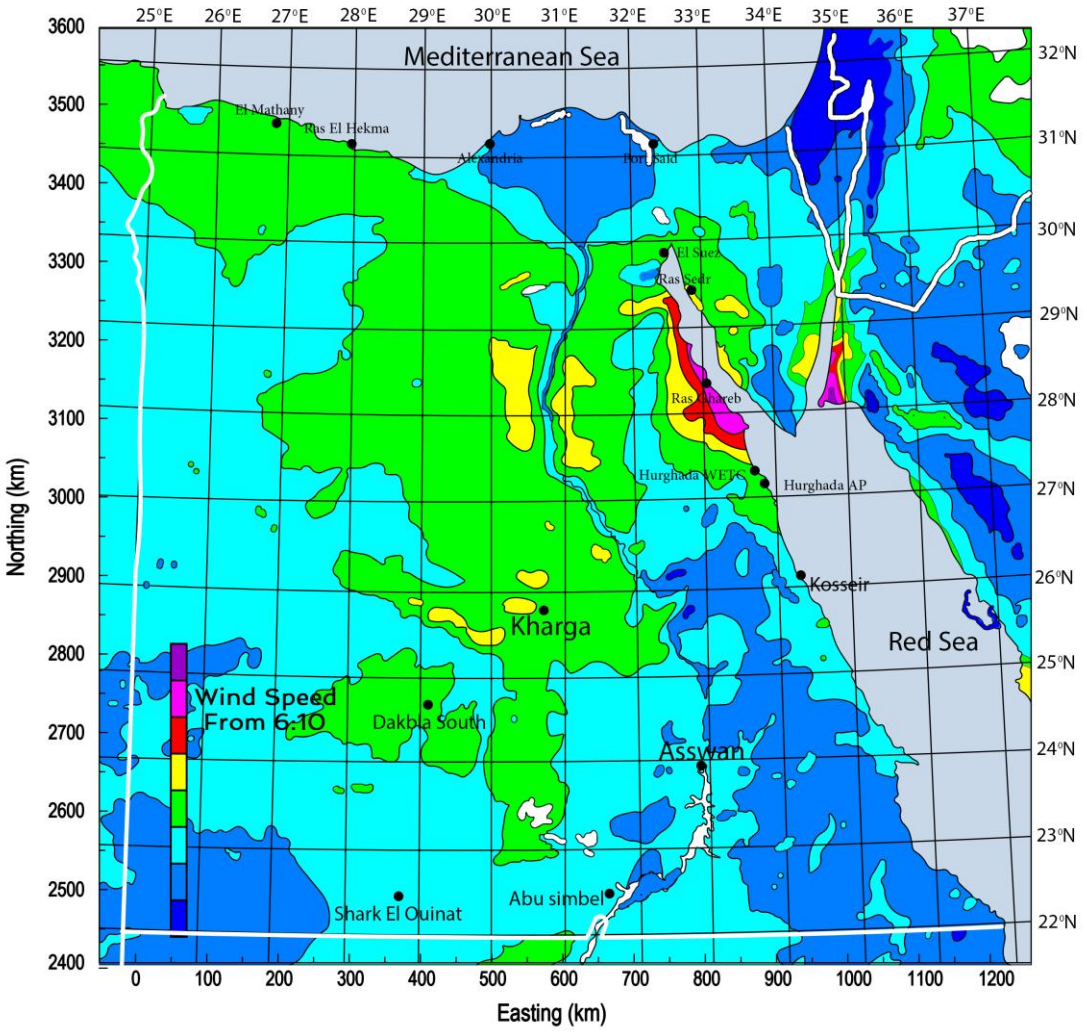

Fig. 3. Wind atlas of Egypt

Atlas results show averaged vertical Direct radiation solar between-2000 3200 kWh /m2/year. the sunshine rate ranging between 9-11 h /Day, which means the availability of investment opportunities in the various areas of the solar energy as shown in Fig. **(4**). The target of EEHC for electric power generation from solar energy through creation capabilities with total capacity of about 3,500 MW by the year 2027 is to produce about 14 billion kWh per year, (of which About 5 billion kWh per year by the year 2020), to provide about 3 million tons of oil equivalent annually and to limit the emission of approximately 7.7 million tons, second of carbon dioxide per year [5,13].

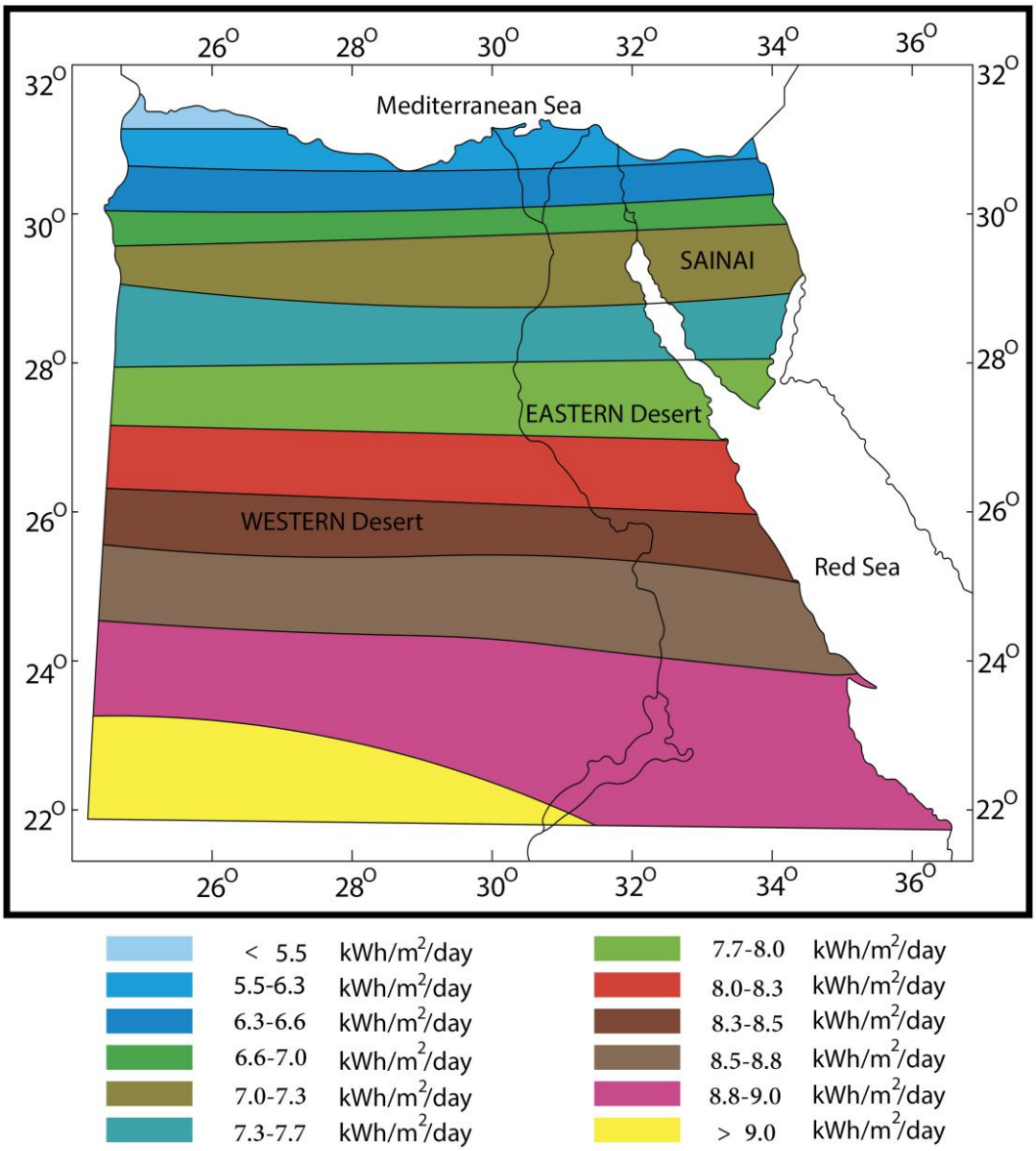

Fig. 4. Solar atlas of Egypt

3. CALCULATING THE EMISSION FACTOR OF THE EGYPTIAN ELECTRICITY SYSTEM.

The Emission Factor of the Egyptian power system can be calculated as a Combined Margin (CM) ($EF_{CM,k}$), consisting of merging between two factors Build Margin (BM) ($EF_{BM,k}$) and operating margin (OM) ($EF_{,OM,k}$) as follows: [15-18]:-

$$EFCM,k=w_{OM}.\ EFOM,k + w_{BM}.\ EFBM,k \qquad (1)$$

the build margin (BM) and operating margin (OM) weightings (w_{BM} and w_{OM}) are selected as the default values for power generation from wind w_{BM}. = 0.25 and w_{OM} = 0.75

3.1. Operating Margin Emission Factor Calculation

The simple OM grid Emission Factor ($EF_{OM,k}$) is calculated as the average CO_2 emissions per unit net electricity generation in Metric ton (t CO_2 / MWh) of all thermal power plants sources that serving the electricity system, and Depends on the type of the fuel used as well as the quantities consumed of the power system as follows [15-18]:

$$EF_K = \frac{\sum_i FC_{i,k}.NCV_{i,k}.EF_{CO_2,i,k}}{EG_{grid,k}} \qquad (2)$$

Where:

$FC_{i,k}$ is the amount of fossil fuel type *i* (in volume or mass units) expended in the electricity system in year *k*;

$NCV_{i,k}$ is the net calorific value (energy content) for each type *i* of fossil fuel in year *k* (in GJ / volume or mass unit) [19].

$EF_{CO2,i,k}$ represents the CO_2 emission factor of each type *i* of fossil fuel in year *k* for the net amount of the delivered and generated electricity to the system by all power plants in (tCO_2/ GJ) [20].

$EG_{grid,k}$ is the amount of electricity that delivered to the system by Sources serving the system, in year *k* (in MWh).

I represents the different types of fossil fuel consumed in power sources in the electricity system in year *k*.

k represents either year for which data is available

Table **1** shows the calculation procedures of the operating margin emission factor ($EF_{,OM,y}$) according to the data available of the Egyptian grid 2015 [1], ($EF_{OM\ ,k}$) amounts to 0.555 tCO_2 / MWh. Energy unit conversion factor from Tonne of Oil Equivalent (toe) to GJ is 41.87 GJ / toe [21].

3.2. Calculate the Build Margin Emission Factor

The emission factor of build margin is calculated as the average CO_2 emissions per unit net electricity generation in Metric ton (t CO_2 / MWh) for sample group of plants (*m*), that have been added most recently which comprises for about 20% of the total electricity generation system (in MWh) and are calculated as follows:

$$EF_K = \frac{\sum_i EG_{m,k}.EF_{EL,,m,k}}{EG_{m,k}} \qquad (3)$$

The emission factor $EF_{EL,m,k}$ of CO_2 for each power plant *m* is calculated as follows:

$$EF_K = \frac{\sum_i FC_{i,m,k}.NCV_{i,k}.EF_{CO_2,i,k}}{EG_{m,k}} \qquad (4)$$

Table 1: Simple OM Emission Factor Calculation, 2015

Step of Calculation/ Data Item	**Parameter**	**Unit**	**Year 2015**
A. Fuel consumption			
Fuel consumed by thermal plants (mass units)	$FC_{i,k}$	ktoe	34073
Natural Gas	$FC_{NatGas,k}$	ktoe	25027
Light Fuel Oil	$FC_{LFO,k}$	ktoe	478
Heavy Fuel Oil	$FC_{HFO,k}$	ktoe	8568
B. The Emission Coefficient of CO_2			
Emission Factor of CO_2	$EF_{CO2,ik}$		
Natural Gas	$EF_{CO2,NatGas}$	t CO_2 / TJ	54.3
Light Fuel Oil	$EF_{CO2,LFO}$	t CO_2 / TJ	72.6
Heavy Fuel Oil	$EF_{CO2,HFO}$	t CO_2 / TJ	75.5
C. Electricity Delivered			
Net amount of electricity delivered to the grid	$EG_{grid,k}$	1000 MWh	153829
D. Emission Factor Operating Margin			
Emission Factor OM	$EF_{OM,k}$	tCO_2/MWh	0.555

Where:

$EG_{m,k}$ is the net amount of electricity produced and delivered to the system in year *k* by power plant *m* (in MWh).

$EF_{EL,m,k}$ represents the emission factor of CO_2 in year k by power plant m (in tCO_2/MWh)

m represents the build margin for the power units and are listed in Table **3**

According to the data available of the Egyptian grid [1], the operating Emission Factor for Build Margin $EF_{grid,BM,,k}$ is 0.534 t CO_2 / MWh (see Table **2**).

From (1) the Combined Margin emission factor for the Egyptian grid is calculated as the combination between Build Margin emission factor and Operating Margin emission factor as follows:

$$EF_{CM,2015} = 0.75 \times 0.555 + 0.25 \times 0.534 = 0.55 \ tCO_2/MWh$$

Table 2: The Egyptian Electricity System Build Margin Calculation

Calculation Steps /Item	**Parameter**	**Unit**	**Yea 2015**
The total emissions of l CO_2 from BM units	$EG_{m2015}\, x$ $EF_{EL,m,2015}$	1000 tCO_2	18058.49
Total net electricity delivered by BM units	$\Sigma\, EG_{m,2015}$	1000 MWh	33780
BM Emission Factor	$EF_{grid,BM,2015}$	tCO_2/MWh	0.534

4. CALCULATION THE EMISSION REDUCTIONS OF THE EGYPTIAN GRID

The annual CO_2 Emission Reductions ER_k by renewable energy in Egypt by 2015 (wind and solar) were obtained by multiplying the annual electricity delivered from the renewable energy with the EEHC system's combined margin emission factor EF_{2015}

$$ER_k = EG_k \times EF_{CM,k} \qquad (5)$$

ER_{2015} = 1444 GWh/annual × 0.55 t CO_2/MWh = 794200 t CO_2/annual

The Certified Emission Reduction (CER) is = 8.5 ×794200 =6750700 €

5. FUTURE WIND PROJECTS BENEFITS

Based on previous analysis, Renewable Energy has a lot of benefits. One of the most important benefits in regard to environment is that it reduces the emission of carbon dioxide to 794200 t CO_2/a in 2015. In economic terms, this decreased up to 6750700 € in 2015, considering that CER price is 8.5 €/ t CO_2 [22,23]. It also reduced 440 toe of total fuel consumption. The expected impacts of the future expansion of wind energy in accordance with the EEHC schedule in terms of fuel saving, the emission reduction of carbon dioxide and CER price/ year from 2015 to 2022 are listed in Table **4** and shown in Fig. (**5**).

Table 3 Sample Group Calculation for The Emission Factor of Build Margin.

BM Sample Group (*m*)	**Emissions of CO2**	**Emission Factor of CO2**	**Generation**	**Fuel Consumption**
Plant/Unit	*EGm,k x EFEL,m,k*	*EFEL,m,k*	*EGm,k*	*FCNatGas,m,k*
	$ktCO_2$	tCO_2/MWh	1000 MWh	ktoe
N.Giza	1157.014	692.8	1670	510
06-Oct.	1823.998	626.8	2910	804
Ain-Sokhna	1930.625	504.1	3830	851
Benha	1744.595	394.0	4428	769
A-Kir	3480.115	512.5	6791	1534
Domiat-West	1978.266	607.2	3258	872
Domiat-Gas	1944.236	623.2	3120	857
Shabab	2688.355	628.9	4275	1185
Kurimat-2	1311.282	374.9	3498	578
Total	18058.49		33780	7960

Table 4: Future Wind Projects

year	Annual Increase	Total Installed Capacity	Expected Annual Generation (GWh)	ER(t CO_2)×10^3	CER price (€)	Fuel Reduction (ktoe)
2016	545	545	1444	794.2	6,750,700	339.7
2017	710	1250	4687.5	2578.1	21,914,062	1102.7
2018	1000	2250	8437.5	4640.6	39,445,312	1984.9
2019	900	3150	11812.5	6496.9	55,223,437	2778.9
2020	1050	4200	15750	8662.5	73,631,250	3705.2
2021	1500	5700	21375	11756.3	99,928,125	5028.5
2022	1500	7200	27000	14850.0	126,225,000	6351.7
TOTAL		7200		49778.6	423,117,887	21292

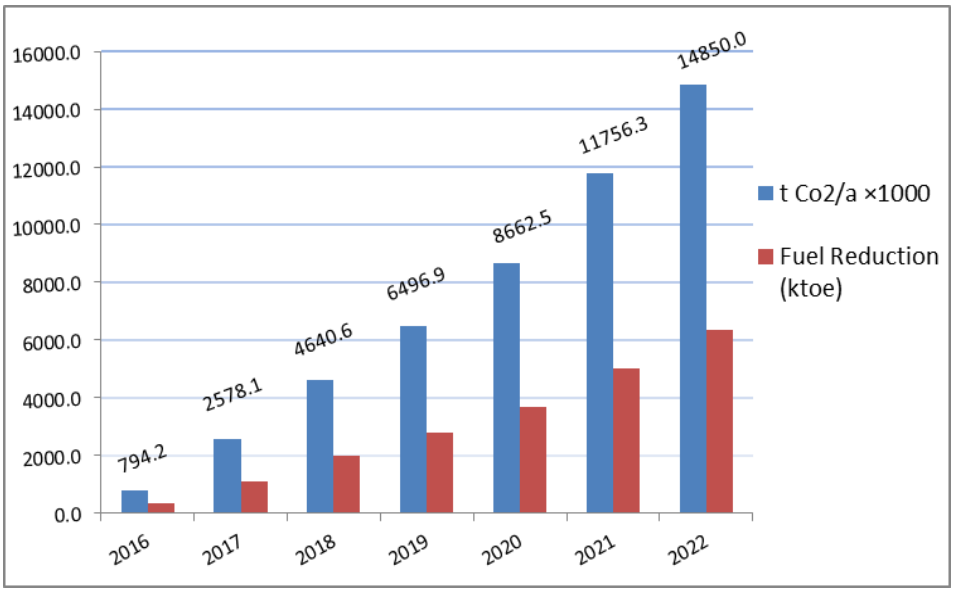

Fig. 5. Expected annual CO_2 emission reduction and fuel saved in Egypt.

CONCLUSION

This paper discussed the electrical energy production of the Egyptian grid according to the annual reports of EEHC. It showed that the thermal energy is the main energy and represents 90% of the total energy produced. It used up to 34110 ktoe in 2015. The paper indicated that the Egyptian plan is to expand the use of renewable energy. Also it highlighted the benefits of expanding the use of renewable energy in the event of implementation of these future projects, through calculating the Egyptian grid

emission factor. The paper gave an example of implementation through the expected wind power projects with a total capacity of up to 7200 MW in 2022. The study concluded that the expected emission reduction of carbon dioxide is up to 49778.6 t CO_2. This decreases, in economic terms, up to 423,117,887 considering that CER price is (8.5 €/ t CO_2). Finally the expected saved fuel reached 21292 ktoe.

ACKNOWLEDGMENT

The authors gratefully acknowledge the contributions of the Egyptian Electricity Holding Company for their data.

REFERENCES

[1] Arab republic of Egypt, Ministry of Electricity and Energy, Egyptian Electricity Holding Company, (Annual Report 2014-2015, Arabic Version, 2015). http://www.moee.gov.eg. Assessed April 2015

[2] Arab republic of Egypt, Ministry of Electricity and Energy, Egyptian Electricity Holding Company, (Annual Report 2013-2014, Arabic Version, 2014). http://www.moee.gov.eg. Assessed April 2014

[3] Arab republic of Egypt, Ministry of Electricity and Energy, Egyptian Electricity Holding Company, (Annual Report 2012-2013, Arabic Version, 2013). http://www.moee.gov.eg. Assessed April 2013

[4] Arab republic of Egypt, Ministry of Electricity and Energy, Egyptian Electricity Holding Company, (Annual Report 2005-2006", Arabic Version, 2006). http://www.moee.gov.eg. Assessed April 2006

[5] The official website of the ministry of Electricity and Energy, www.moee.gov.eg

[6] El Sayed T., Hany E., Mohamed M, An Integrated Protective Scheme for a multi- ended Egyptian Transmission Line using Radial Basis, The International Conference on Power Systems Transients (IPST'05), Montreal, Canada, June 19-23, (2005).

[7] A. Alwadie, A. M. Abdel-Hamid, Modeling and simulation of a unified power system incorporating large scale wind farms via open source code package, International Conference on Renewable Energies and Power Quality, (ICREPQ'12), Santiago de Compostela, Spain, 28th to 30th March, (2012).

[8] Lahmeyer International Group, Wind parks in the Desert, Information on The Lahmeyer International Group, No. 50, August, (2005).

[9] Bothayna R, Wind energy in Egypt, ESI AFRICA, ISSUE 3, (2006).

[10] A. M. Ashour, Wind energy in Egypt, DEWI Magazine, Nr. 17, August, (2000).

[11] Mortensen**,** G. Niels, S. Said, Wind atlas for Egypt, Proceedings of the Third Middle East-North Africa Renewable Energy Conference (on CD-ROM), (2006).

[12] Arab republic of Egypt, Ministry of Electricity and Energy, New and Renewable Energy Authority (NREA), (Annual Report 2007-2008, Arabic Version, 2008). http://www.nrea.gov.eg/arabic1.html . Assessed April 2008

[13] Arab republic of Egypt, Ministry of Electricity and Energy, New and Renewable Energy Authority (NREA), (Annual Report 2012-2013, Arabic Version, 2013). Available from http://www.nrea.gov.eg/arabic1.html . Assessed April 2013

[14] Tawfic A. M, Baseline for Japanese wind power plant in zafarana project (Arab Republic of Egypt), National Renewable Energy Agency (NREA), 2000. http://cdm.unfcc.int/methodologies/process

[15] Clean Development Mechanism, Tool to calculate the emission factor for an electricity system, Version 01.1, EB 35, Annex 12 july, 2008.

[16] Clean Development Mechanism, Tool to calculate the emission factor for an electricity system, Version 02.1, EB 60, Annex 8 November, 2011.

[17] Clean Development Mechanism, Tool to calculate the emission factor for an electricity system, Version 03.0, EB 70, Annex 22 November, 2012.

[18] Clean Development Mechanism, Tool to calculate the emission factor for an electricity system, Version 05.0, EB 87, Annex 9 November, 2015.

[19] Organization for Energy Planning, Energy in Egypt, Conversion Units, 2003/2004.

[20] IPCC, Guidelines for national greenhouse gas inventories, Chapter 1, (2), Energy, Table 1.4, 2006.

[21] Organization for Energy Planning, Energy in Egypt, Conversion Units, Standard Conversion Factor, 2002/2003.

[22] Kyoto Protocol, The united nations frame work convention on climate change, United Nations, 1998

[23] Thomson Reuters, Carbon market monitor, Review of global markets in 2015 and outlook for 2016-2018, January, 2016. Available from: http://climateobserver.org/reports/carbon-market-monitor-america-to-the-rescue/. Assessed January 2016